

# IARPA HFGeo Phase 2 Proposers' Day



**Northrop Grumman Information Systems /  
ISR Division / Airborne & Terrestrial SIGINT**

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# Topics

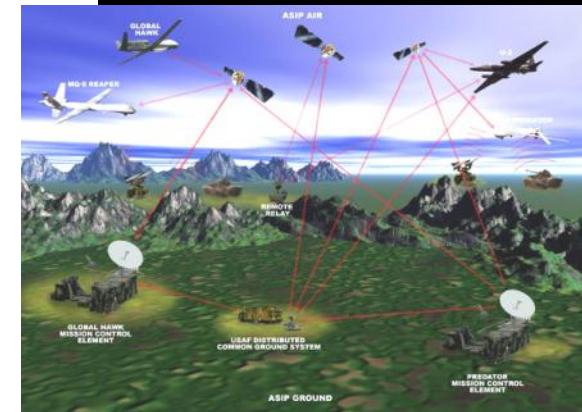
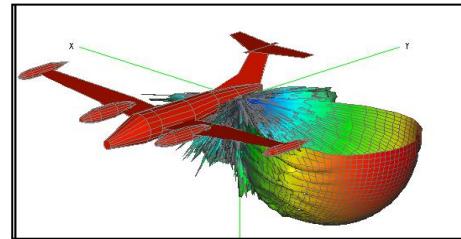
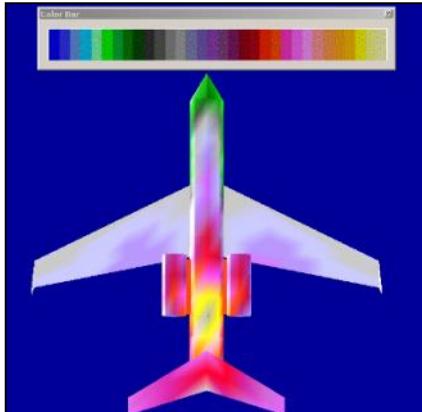
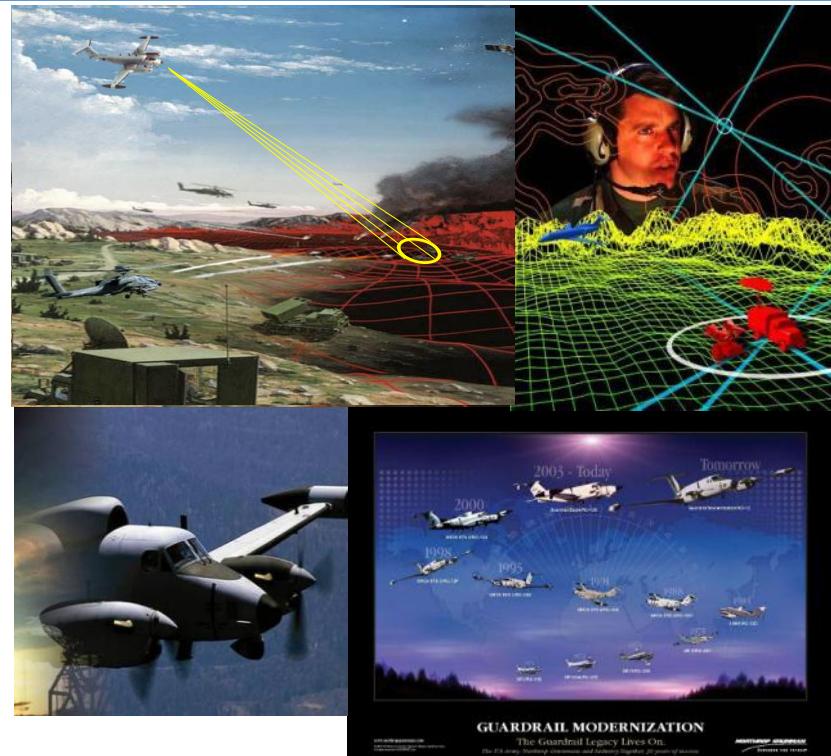
- Introduction
  - NGC and HFGeo Phase 1 Team
- Key Algorithms from HFGeo Phase 1
  - Signal Processing Block Diagram
  - Detection (GLRT) with Lightning Mitigation
  - External Calibration
  - Self-Calibration with Modified MUSIC
  - Cross Ambiguity Function
  - Ray Tracing and Associated Databases
  - Geo-Combining
- Matlab Testbed
  - Operator Data Analysis Tools

# A&TS Systems Capabilities

**40+ Years Experience, SIGINT & Multi-INT Integration, Sensors, Services**

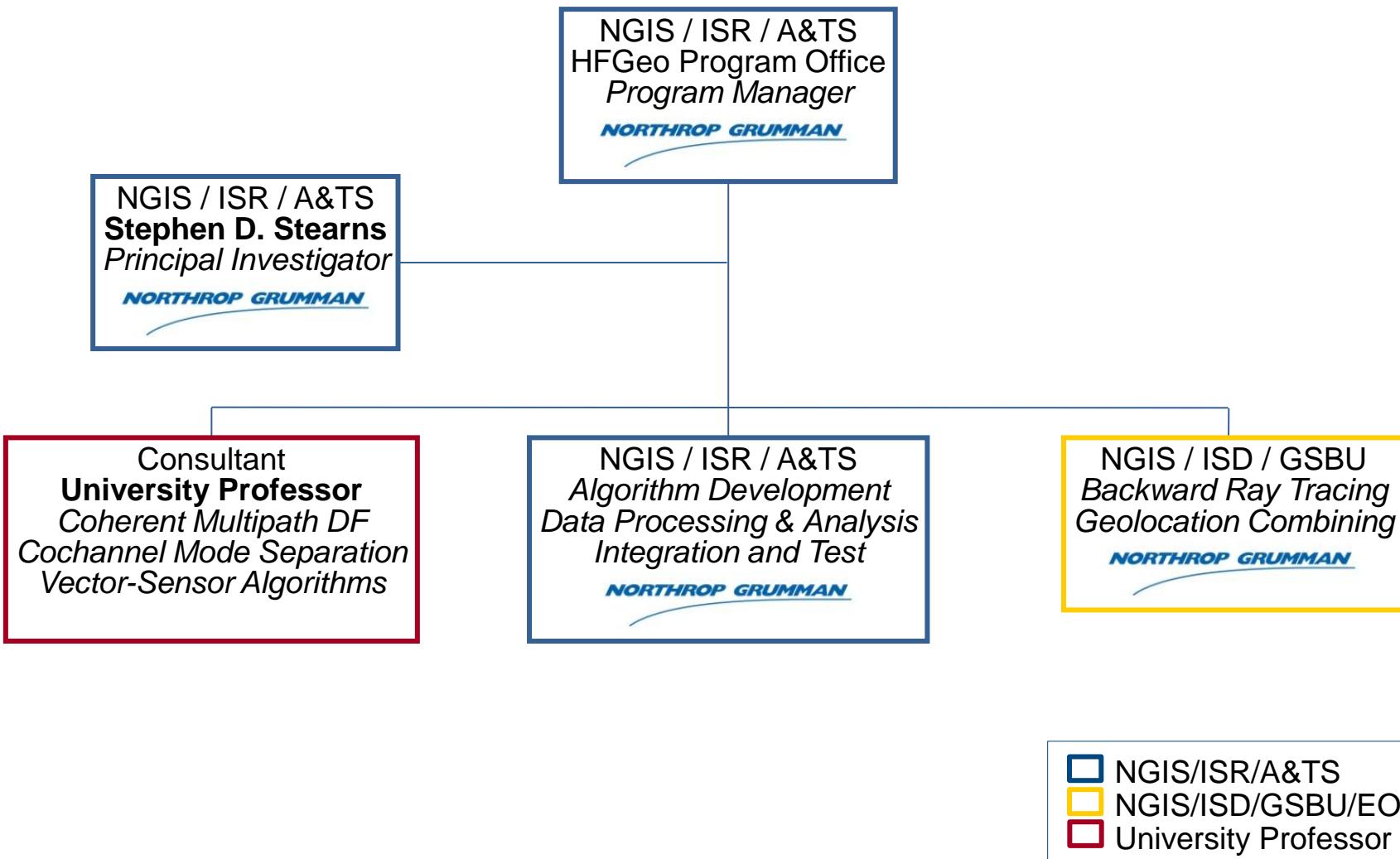
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- Located in Northern California (Sacramento/San Jose)
- Design/development of advanced SIGINT systems
  - HW, SW, Systems, EMI/EMC, Cosite Engineering, SWAP
  - Fabrication, Assembly, Test, Aircraft Integration, Flight Test
- End to end System/SIGINT Integration
- Processing, Exploit., Operator Tools, Dissemination (PED)
- Special Signal Exploitation (XM and special processing)
- Geolocation, Signal ID, Interference mitigation
- Antennas and antenna modeling
- Flight Test at A&TS Sacramento facility
- Complete life-cycle support – design and development through delivery, ILS, field support, and upgrades



# Introducing Our Team

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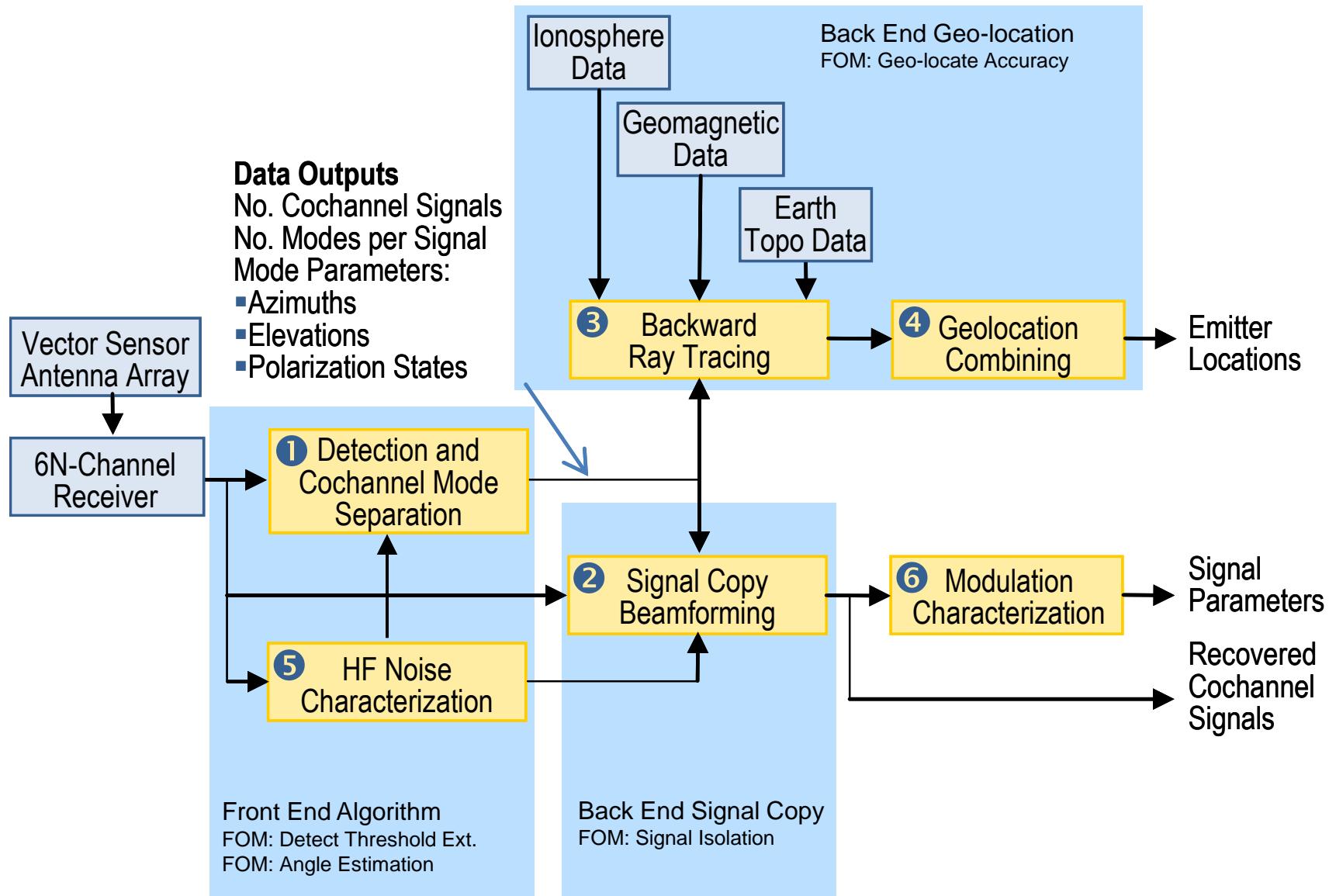


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# **Key Algorithms from HFGeo Phase 1**

# Signal Processing Flow Diagram



# Generalized Likelihood Ratio Detector

- Binary hypothesis testing

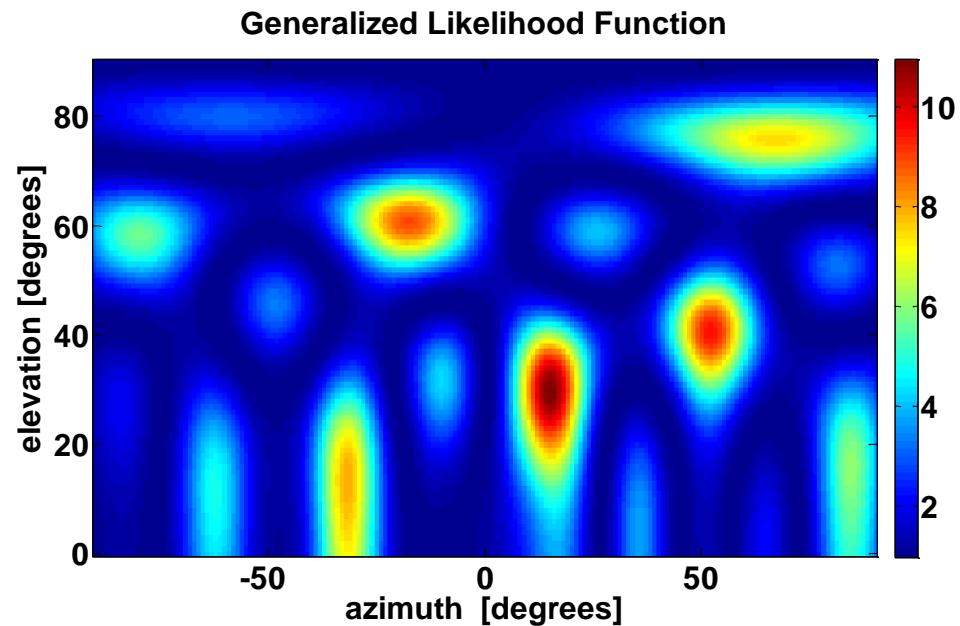
$$H_0 \quad \mathbf{y}[n] = \mathbf{w}[n], \quad \text{for } n = 1, \dots, N$$

$$H_1 \quad \mathbf{y}[n] = \mathbf{A}(\theta, \psi) \eta s[n] + \mathbf{w}[n], \quad \text{for } n = 1, \dots, N$$

- Generalized Likelihood Ratio

$$LR(\mathbf{y}) = \frac{\max_{\mathbf{p}_1} \{f(\mathbf{y}|H_1, \mathbf{p}_1)\}}{f(\mathbf{y}|H_0)}$$

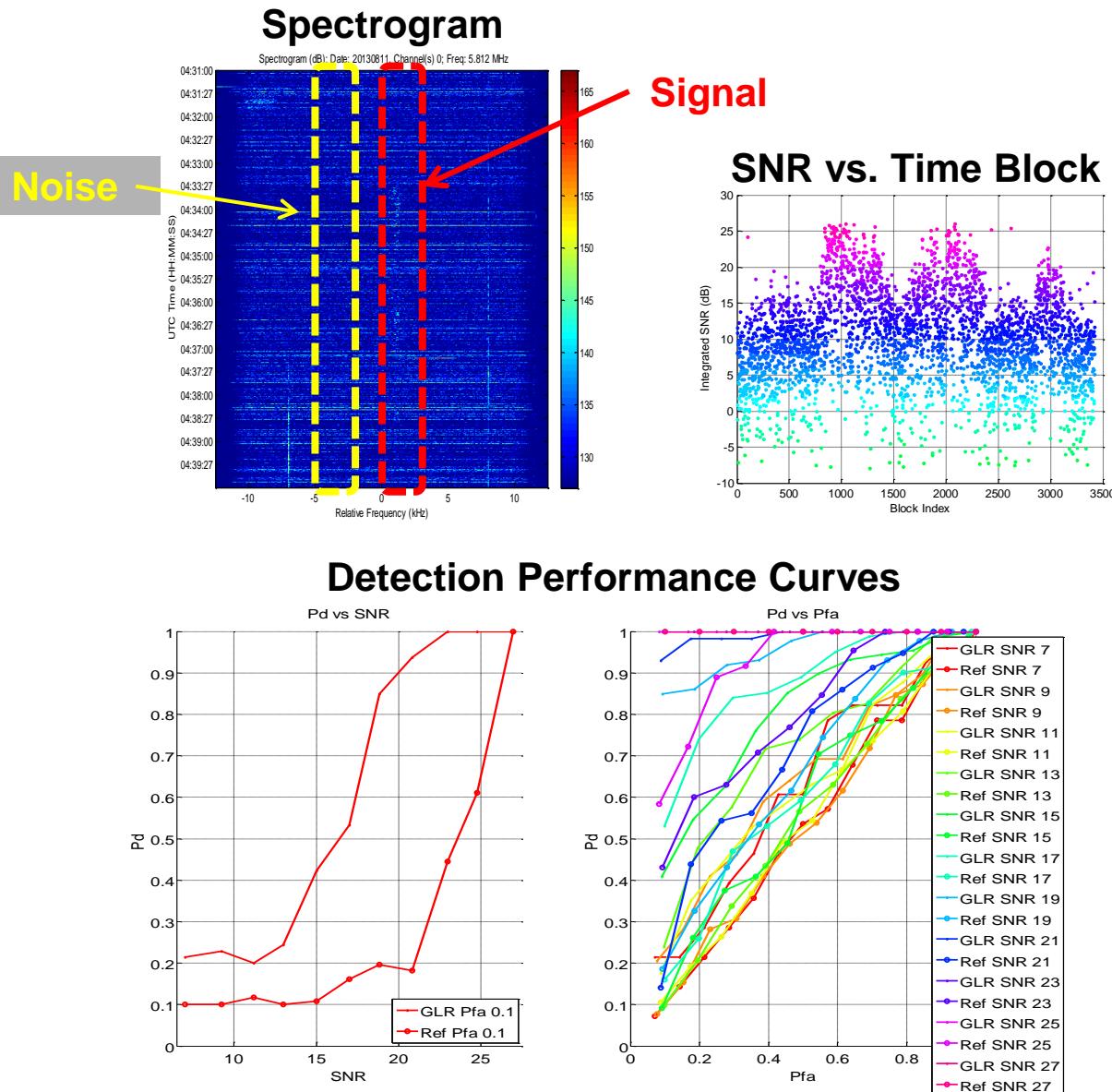
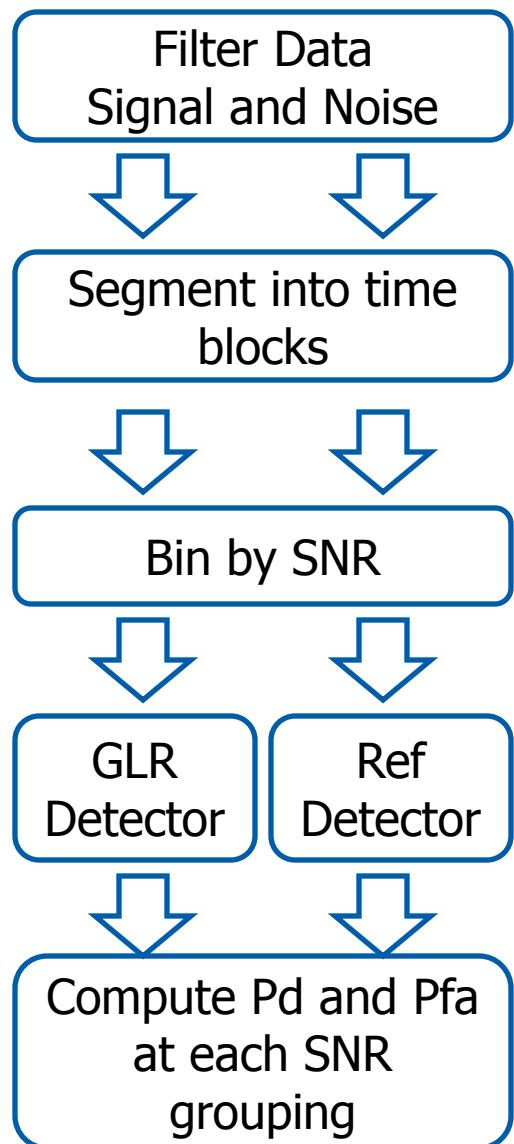
where  $\mathbf{p}_1 = [\eta, \theta, \psi]$



The detection statistic is the output power of a beamformer maximized over azimuth, elevation, and polarization. It uses the array to mitigate noise directionality.

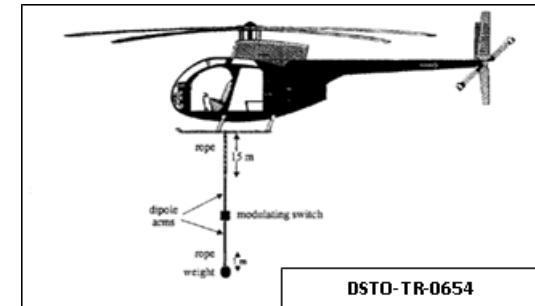
# Detection Data Processing Flow

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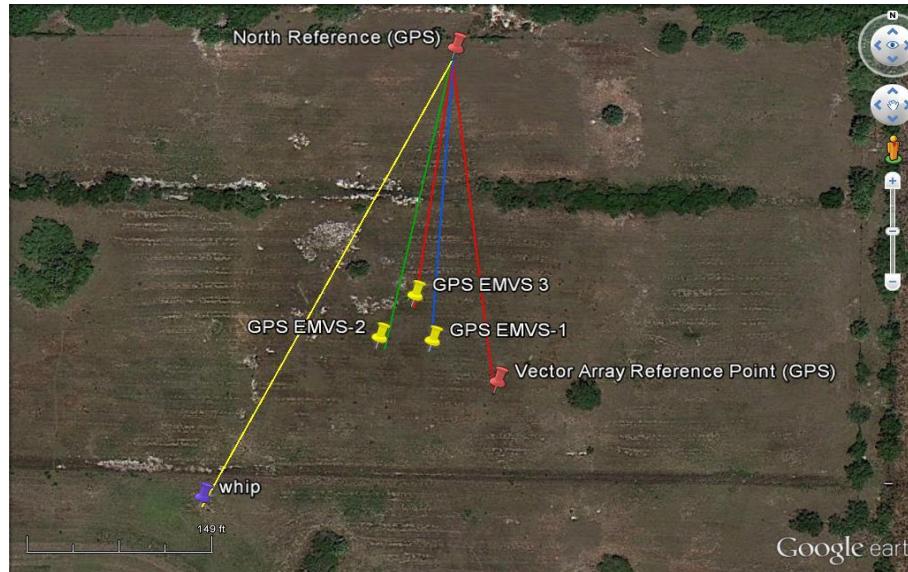
# Calibration using External Source

- Estimate relative gain and phase offsets for each antenna element at a given frequency from a source at known position
- Assume simple manifold error model
  - Complex receiver channel gains (independent of direction)
  - Manifold correction can be estimated from one or more calibration signals if present
- Conceptual algorithm with single calibration source
  - Step 1: Look up manifold vector
  - Step 2: Obtain signal vector from calibration data
  - Step 3: Compute manifold correction



# Calibration Summary and Conclusions

- Calibration data such as from the whip significantly improves AOA estimation
  - AOA estimates of helicopter transmitter improved with whip-based correction
- Spatially diverse calibration data is useful for manifold analysis and leads to valuable insight on system performance
  - Future systems would benefit from static (one-time) and dynamic (during operation) calibration to measure and compensate for manifold error that changes over time

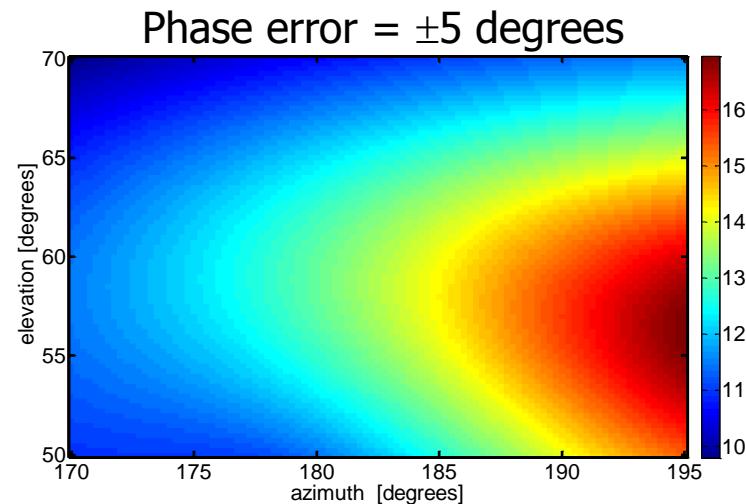
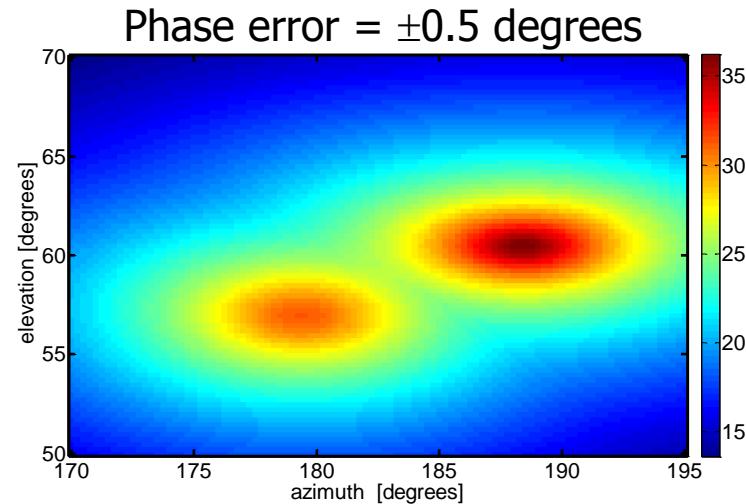
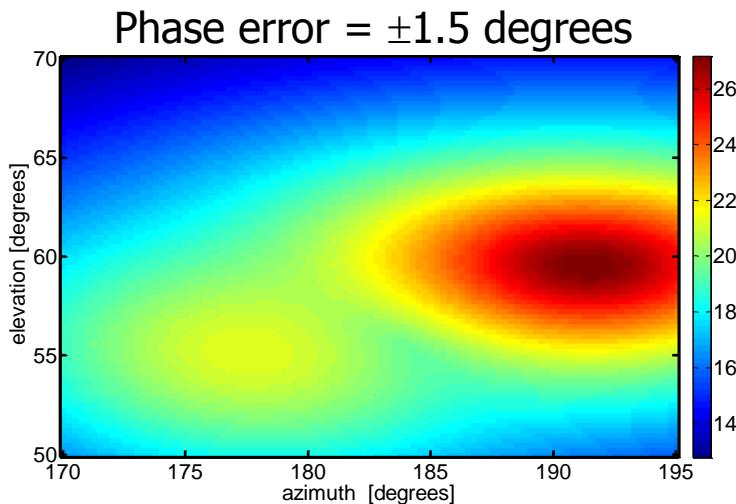
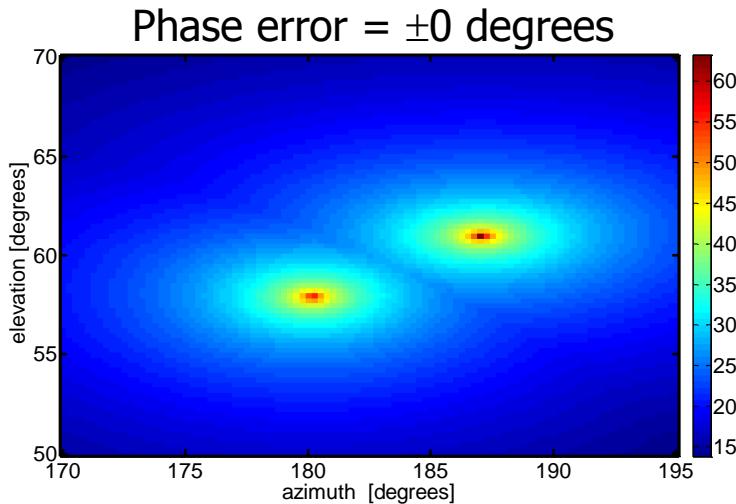


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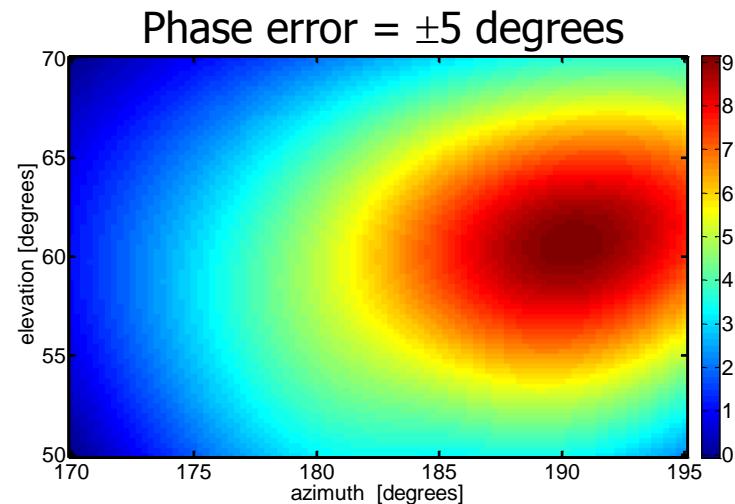
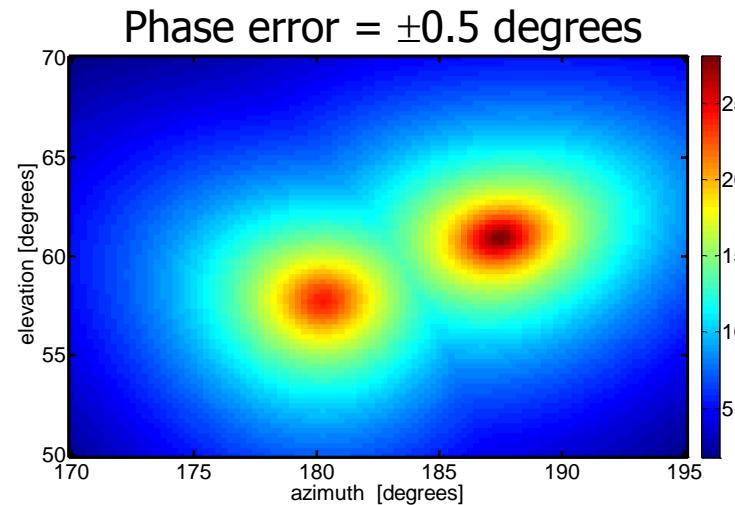
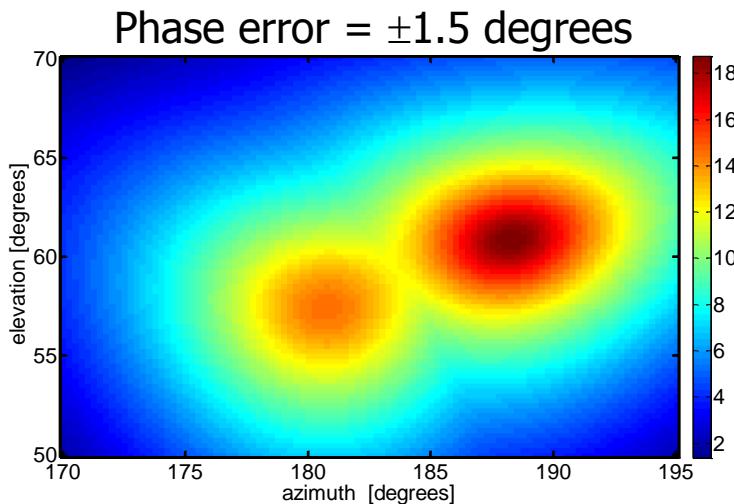
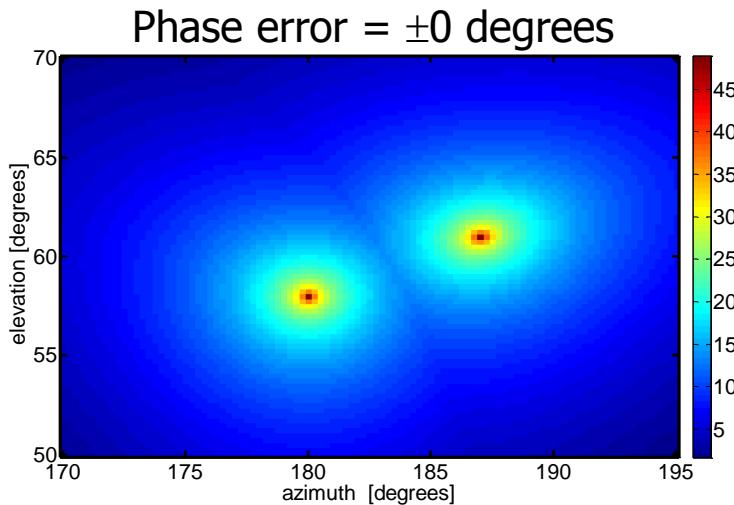
# **Direction of Arrival Algorithms**

# Effect of Manifold Error on MUSIC Spectra of 1-EMVS Array



As array manifold error increases, resolution is lost.

# Effect of Manifold Error on MUSIC Spectra of 3-EMVS Array



As array manifold error increases, resolution is lost.

# Self-Calibration Algorithm

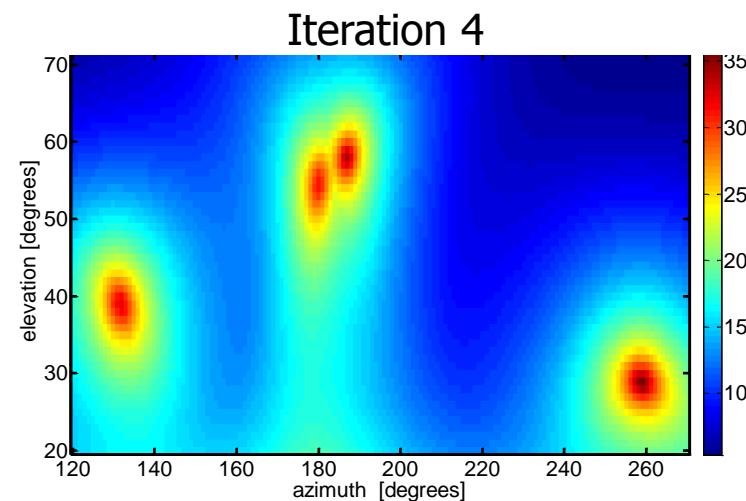
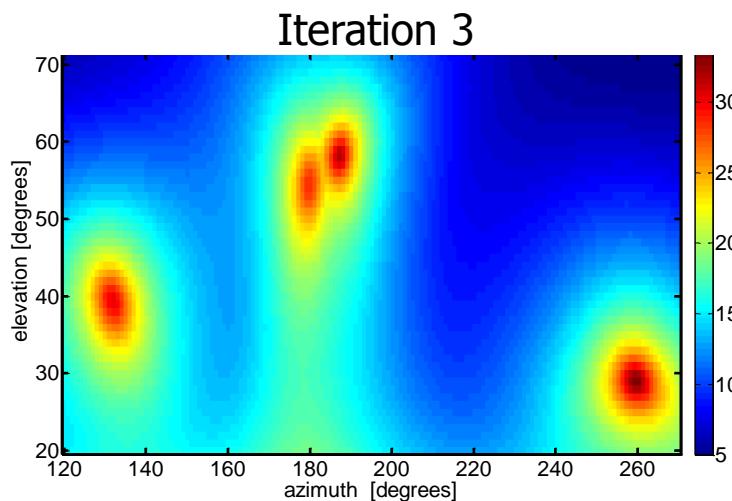
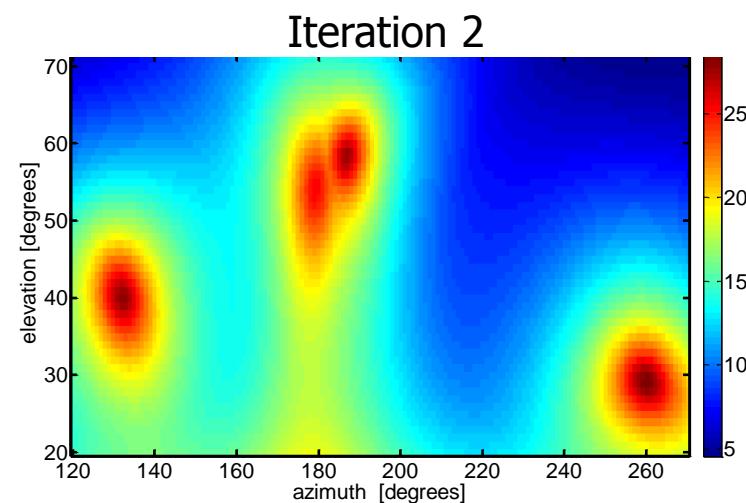
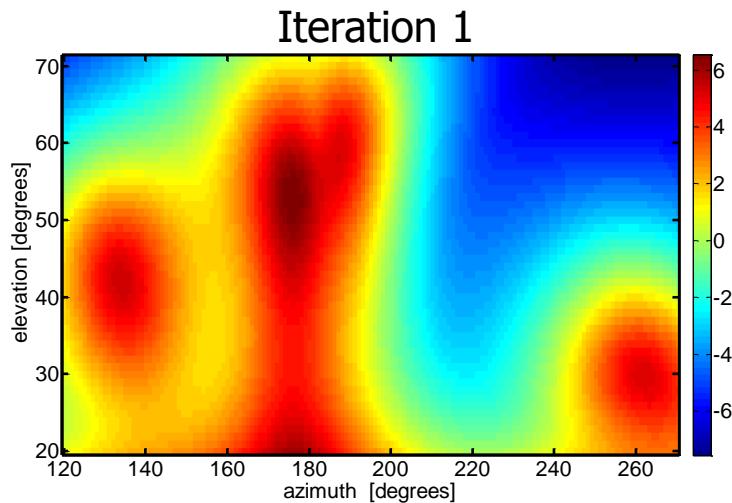


- Self-Cal algorithm jointly solves for both angle of arrival and array manifold error correction
  - Assumes a parametric model for manifold error
- Algorithm uses a fixed-point iteration in two steps
  - Estimate the azimuth and elevation angles, *given* array manifold error correction
    - Find peaks of the MUSIC spectrum
  - Estimate for the array manifold error correction, *given* the angles of arrival
    - Solve eigenvalue problem
- Each step has a closed form solution; no search is required

# Blind Self calibration with Four Unknown Signals

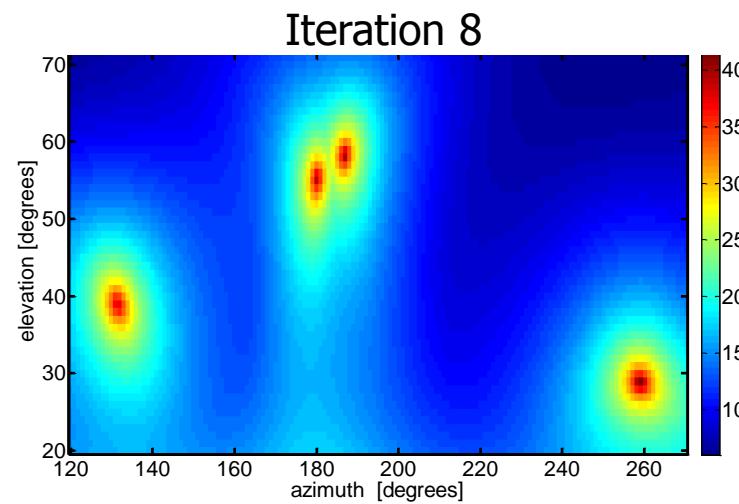
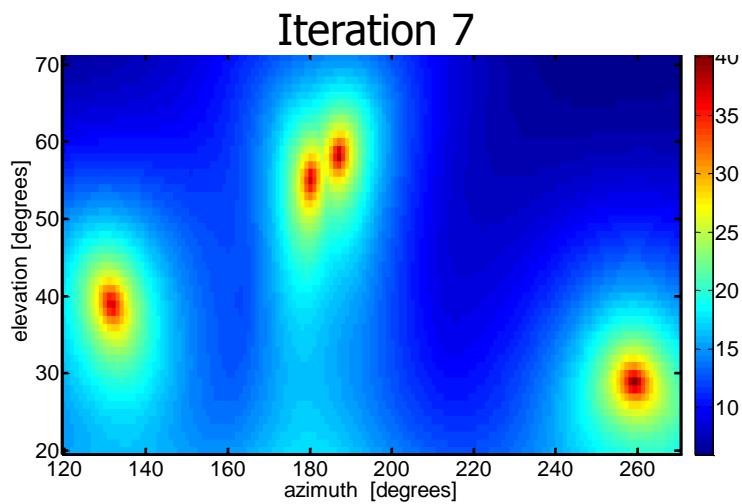
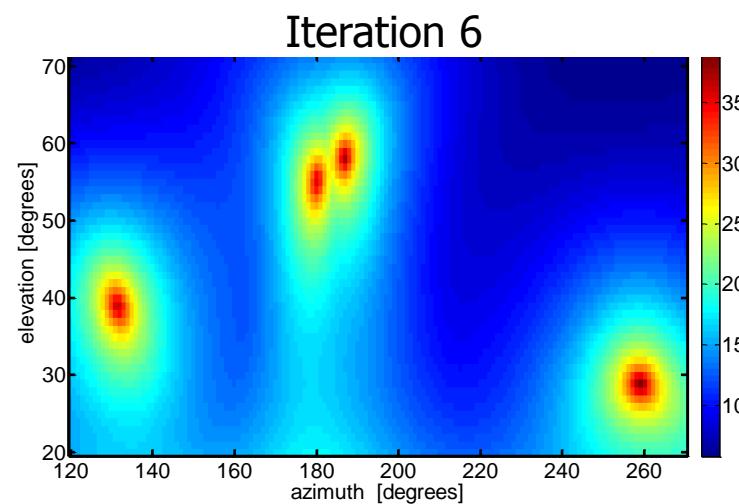
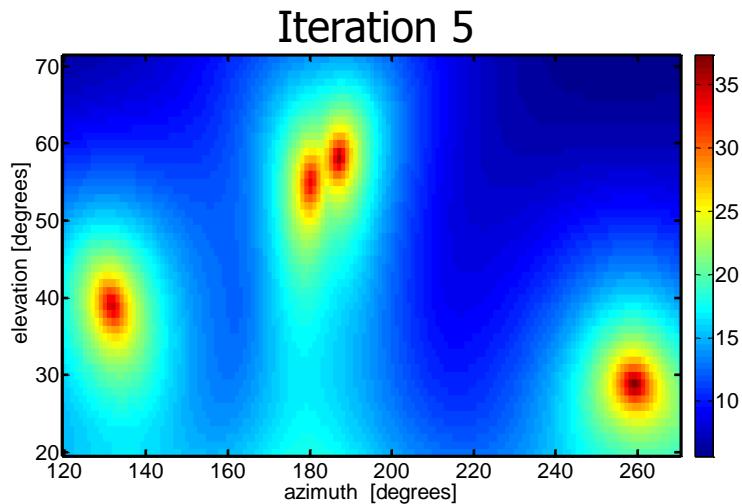
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Phase error =  $\pm 25$  degrees, Amplitude error =  $\pm 1.5$  dB



Self calibration restores resolution lost due to manifold error.

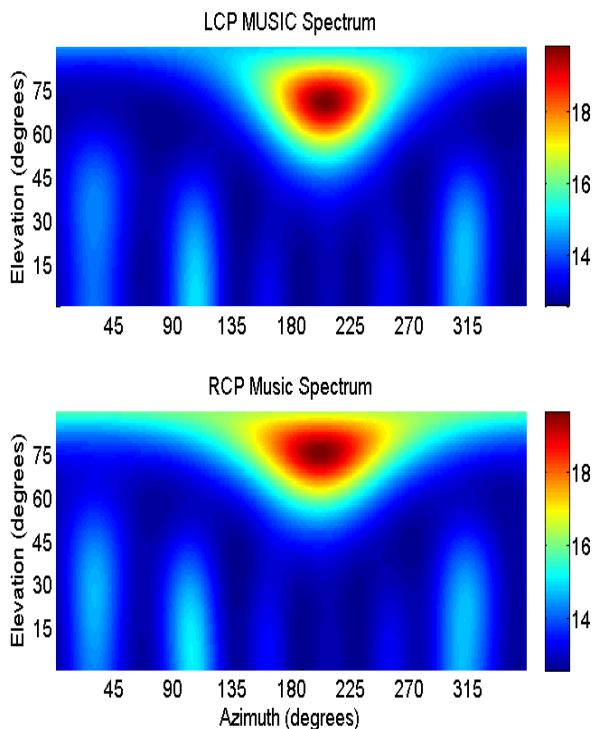
# Example continued



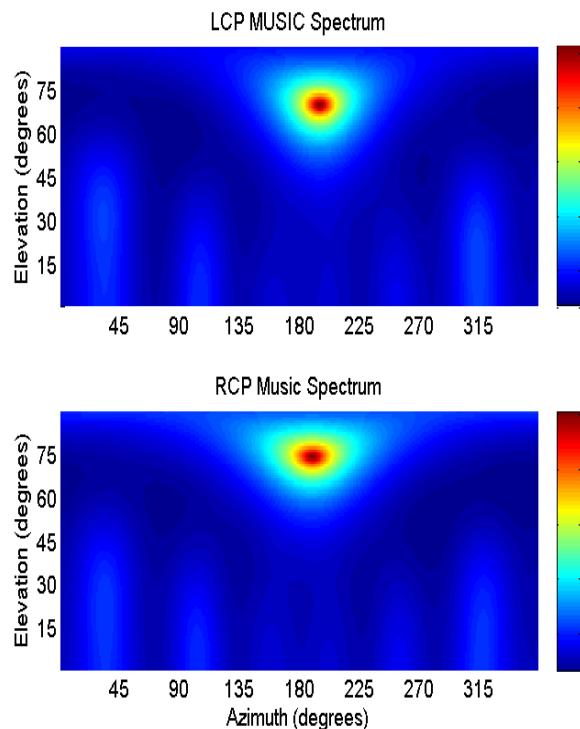
Self calibration restores resolution lost due to manifold error.

# Self-calibration applied to GFI data

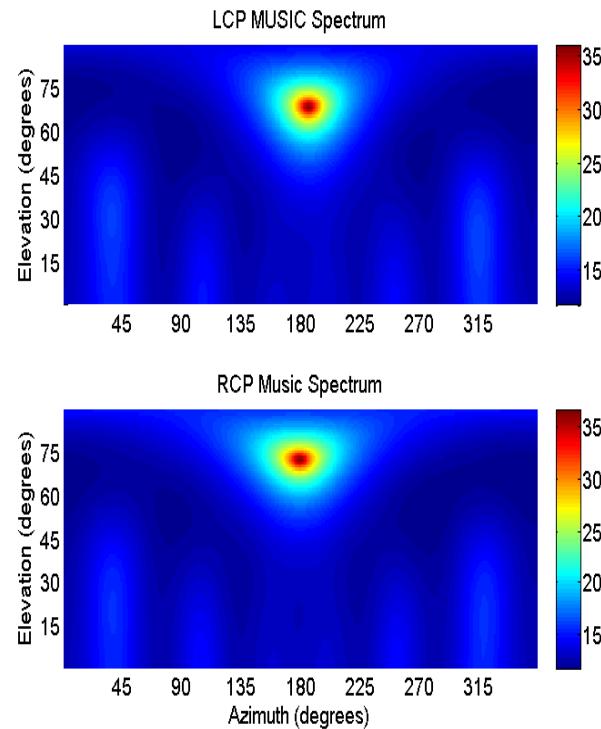
**MUSIC spectrum**



**5 Iterations of self-calibration**



**15 Iterations of self-calibration**

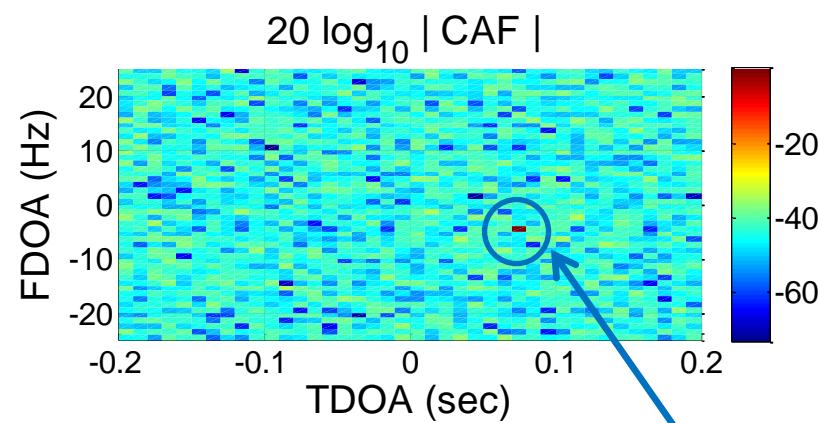


Self calibration iterations increase the heights, sharpness, and resolvability of MUSIC peaks.

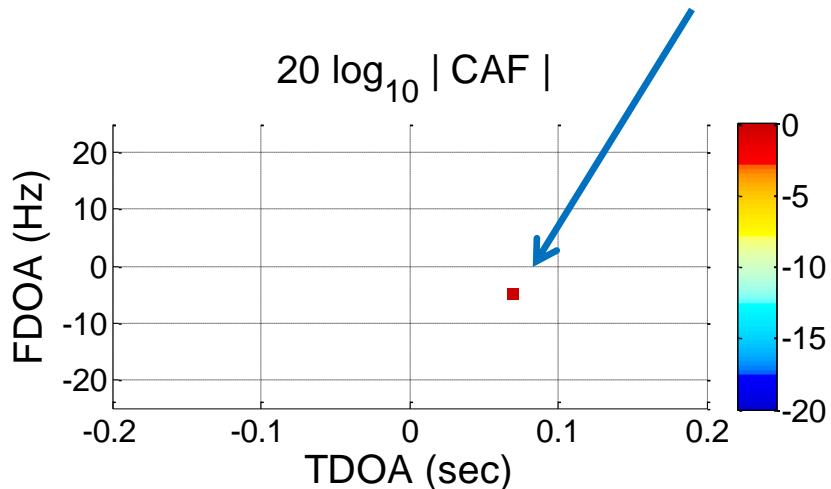
# CAF Processing for AoA Estimation Overview



1. Compute Cross Ambiguity Function (CAF) at each antenna
  - Compute against reference waveform or arbitrary antenna element (blind)
2. Locate TDOA/FDOA points at which to construct signal vectors
  - Find “peaks” in the CAF spectra
  - For each peak, compile entries across antenna elements into signal vector,  $\mathbf{v}_k$
3. Estimate spatial parameters associated with each signal vector,  $\mathbf{v}_k$ 
  - Compute spatial spectrum by “beamforming DF”, matching signal vector to manifold
4. Estimate (optionally) self-calibration manifold correction
  - Iterate between steps 3 and 4 to improve spatial estimates
5. Report signal parameters
  - TDOA, FDOA, azimuth, elevation, polarization



Peaks are narrow and difficult to see  
Plotting adjusted to highlight peaks



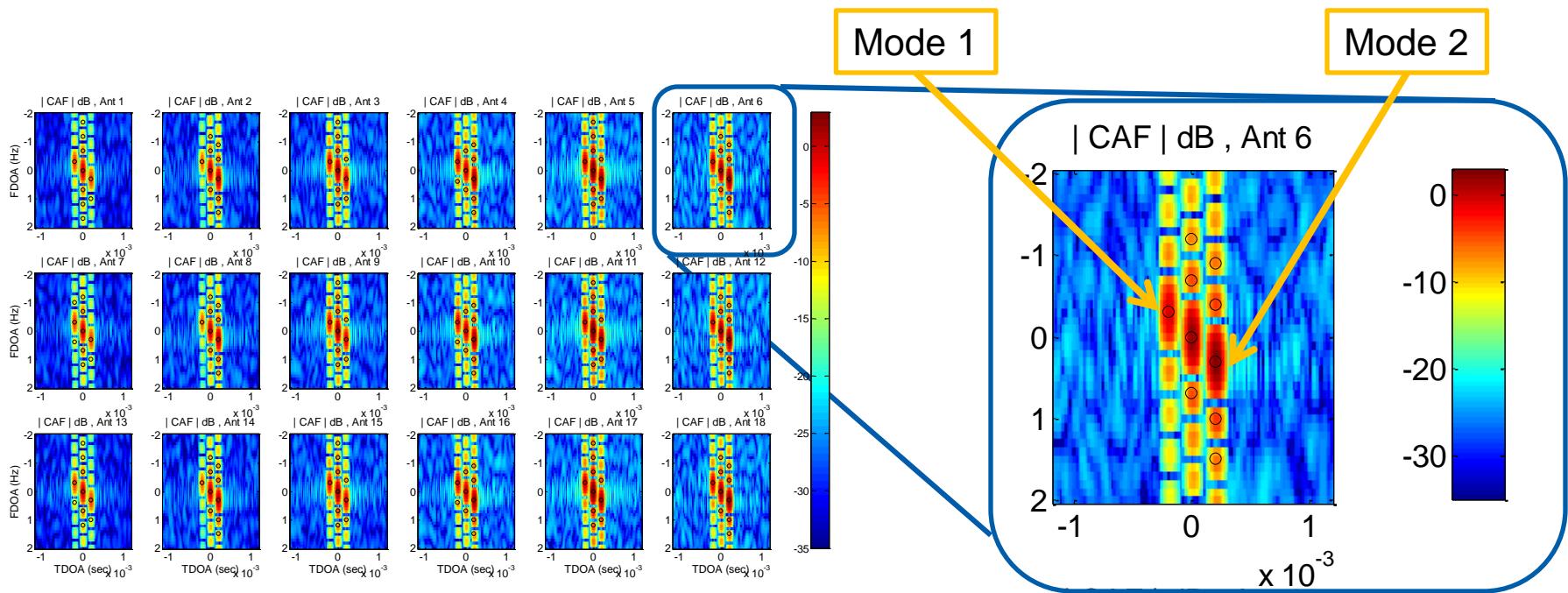
# Blind CAF Processing Simulation

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Simulation: 2 modes of LFMCW (RADAR) waveform

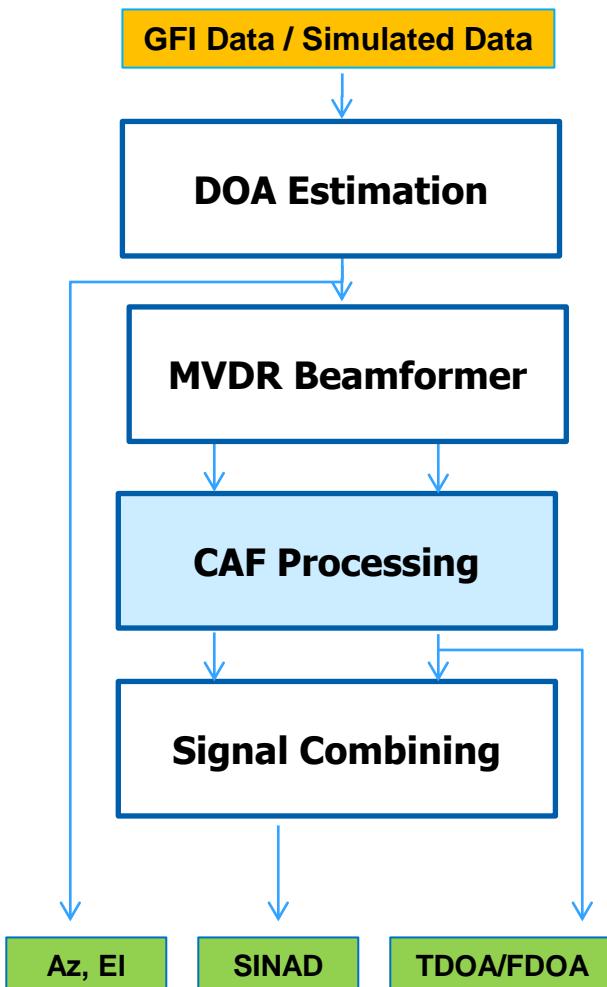
	Az. (deg)	El. (deg)	Pol. E. (deg)	TDOA (ms)	FDOA (Hz)
<b>Mode 1</b>	40.5	50.0	+ 40	--	--
<b>Mode 2</b>	41.5	50.0	- 40	+ 0.200	+ 0.3

Compute CAF at each antenna against arbitrary antenna element (blind)



# CAF for Skywave Mode Association

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- **CAF Processing**

- Enables the association of received modes to independent source signals
- Estimates relative time and Doppler/frequency offsets between modes of the same signal
- Provides frequency and time shifts necessary for combining the received modes of each source signal after beamformer isolation and recovery to realize diversity gain
- Provides insight into performance of DOA estimates and MVDR beamformer performance

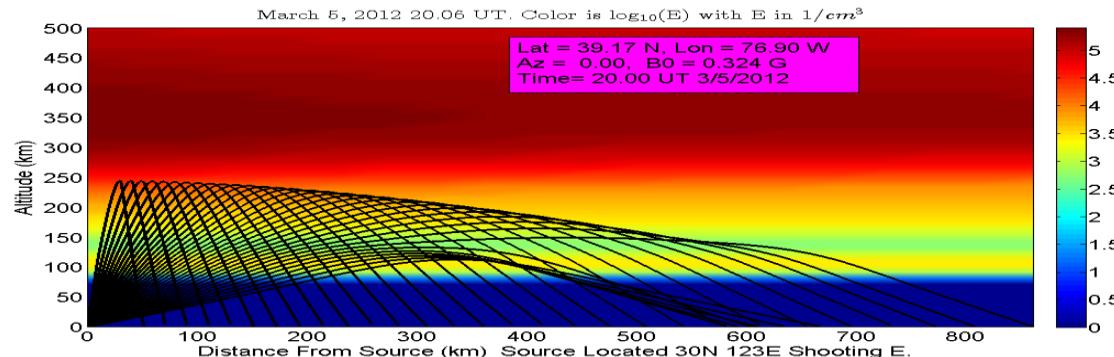
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## **Backward Ray Tracing and Geo-Combining**

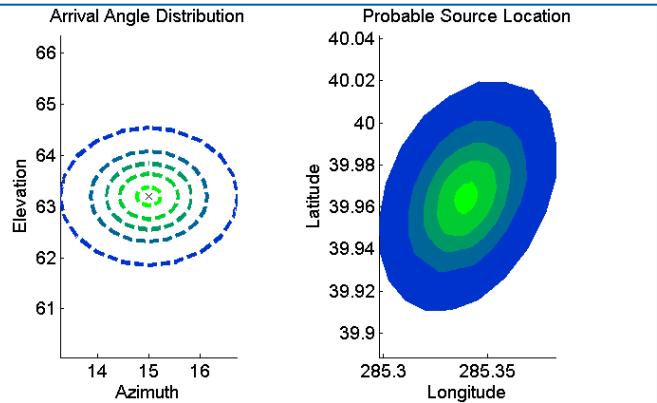
# Backward Ray Tracing

- NGIS ray tracing code -- advances the state of the art
  - Different ray tracing software often produces different results depending on algorithm sophistication
- Innovations include:
  - Eliminates singularities by using new, mathematically rigorous solution of the Haselgrave equations
  - Coded to run on GPU giving fast 3D ray tracing
    - 1000s of 3D rays per second (1 ray/ms) vs. typical speed of ~2 min/3D ray for Proplab-Pro
  - Incorporates highly accurate IGRF geomagnetic field model
    - More accurate magneto-ionic splitting and tracing of O/X modes
  - Incorporates high resolution Earth terrain elevation data for accurate ground bounce direction
  - Incorporates any gridded ionospheric model or database
    - IRI, GAIM, other models, or a combination of models
  - Northrop Grumman scientists are leading research on ionosphere understanding and HF radio wave propagation phenomenology (American Geophysical Union 2014 Fall meeting session – *Advances in Ionospheric Forecasting*)

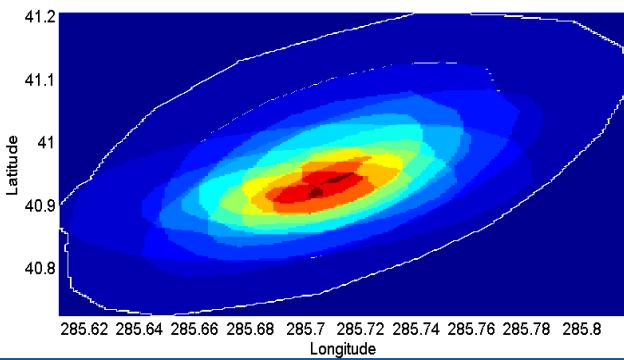


Advanced ray tracing enables improved signal path and characterization analysis.

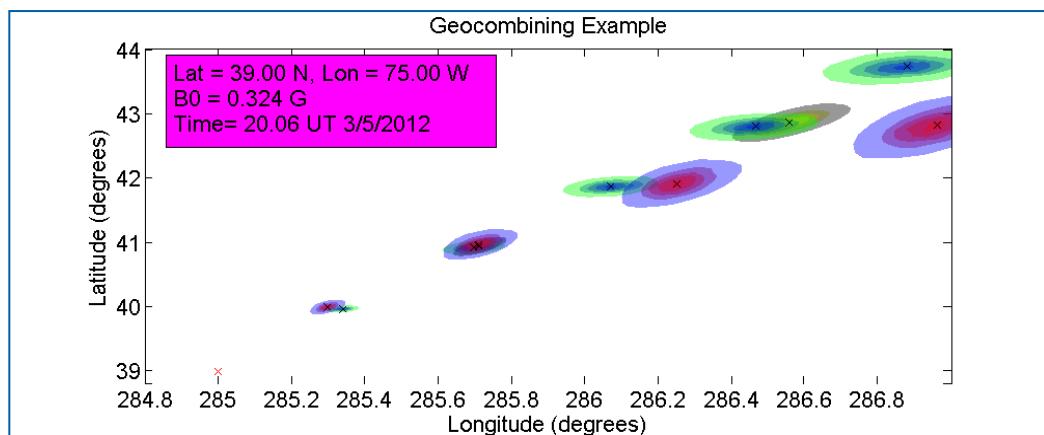
# Geo-Combining Algorithm



Multiple hop information is calculated for several modes. PDFs combined through either weighted sum or weighted product (user choice).



Ray tracing algorithm takes in mode information with median arrival angles and covariance matrices and outputs probable transmitter locations



The “tightest” hop/mode combination output is the max likelihood function value for source location

Refines emitter location estimates by combining candidate locations generated from multiple received O and X modes from all arriving paths (E, F1, F2, ducts, etc.).

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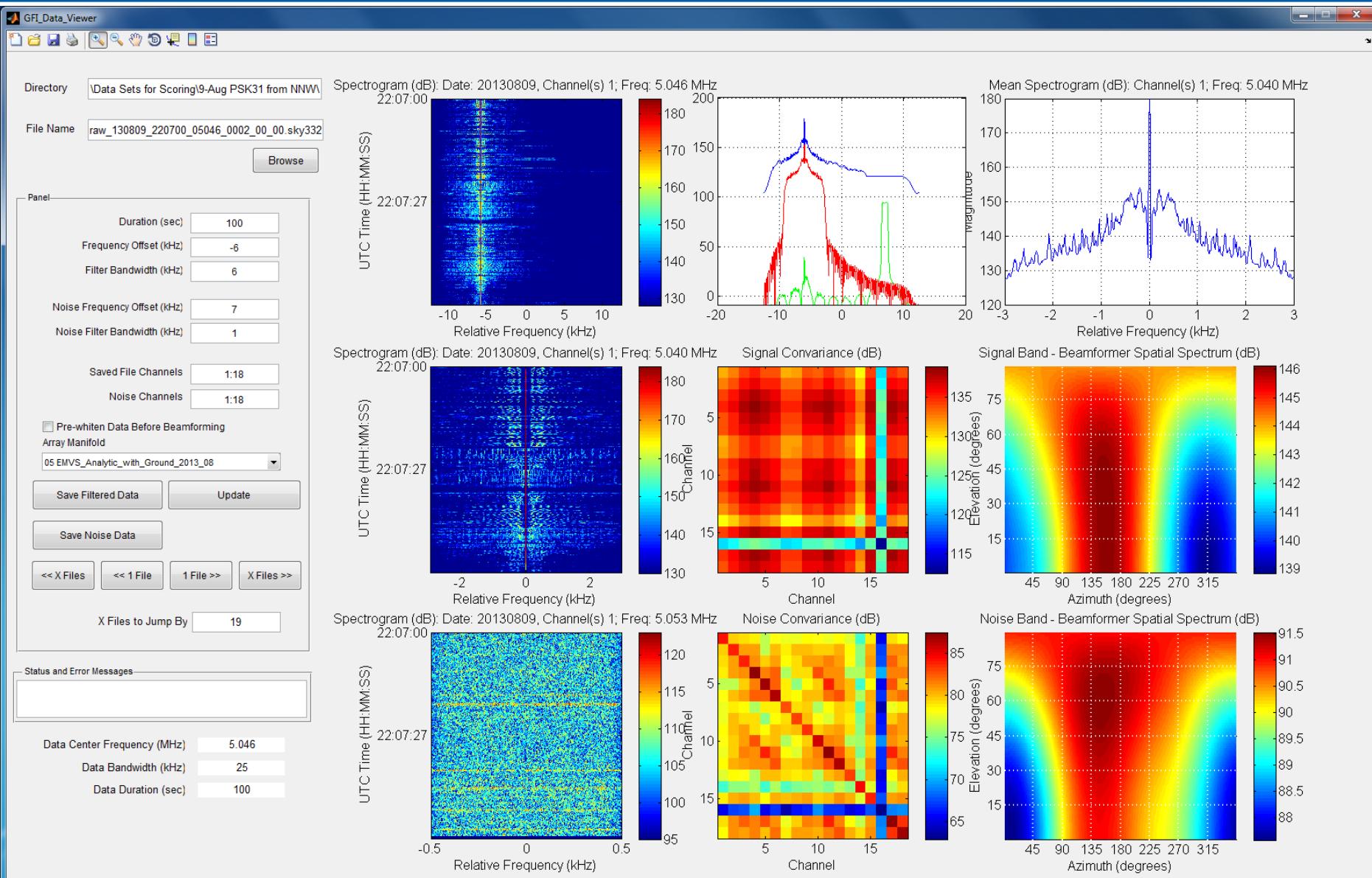
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# Operator Data Analysis Tools

# Data Viewer

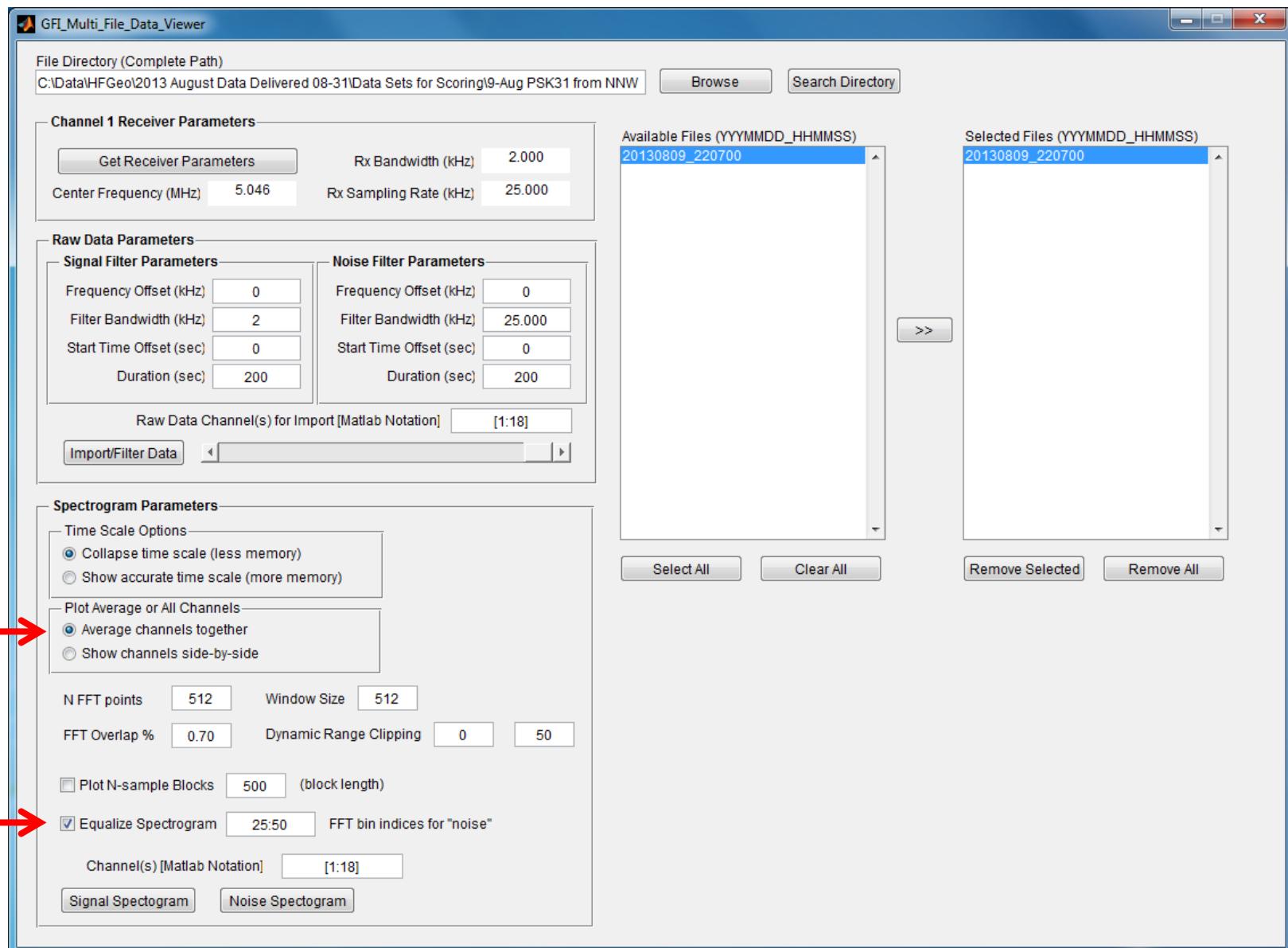
## Spectrogram and Quick-Look Spatial Processing

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# Overview/Multi-Viewer with Detailed Spectrogram Plotting Tools

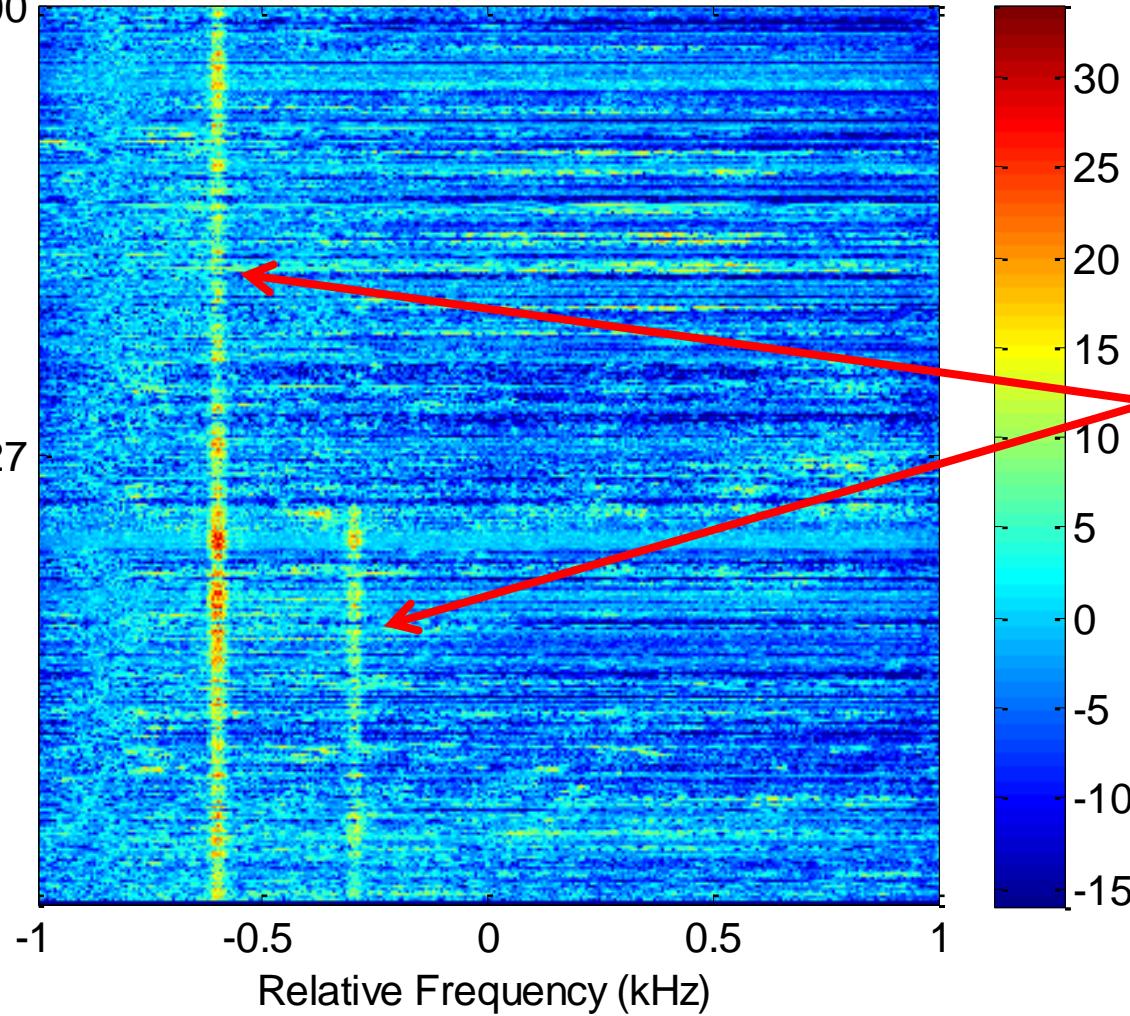
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# Detailed Spectrogram

Spectrogram (dB): Date: 20130809, Channel(s) 0; Freq: 5.046 MHz  
22:07:00

UTC Time (HH:MM:SS)



For example,  
averaging over all  
antennas helps to  
identify two PSK  
signals in the data

# Contact Information



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